PCT/DK 03/00443

Rec'd PCT/PTO 22 DEC 2004

REC'D 30 JUL 2003

WIPO PCT

Kongeriget Danmark

Patent application No.: PA 2002 00986

Date of filing: 26 June 2002

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Title: Dual porosity filter

IPC: -

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Patent- og Varemærkestyrelsen
Økonomi- og Erhvervsministeriet

18 July 2003

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PATENT- OG VAREMÆRKESTYRELSEN

Dual porosity filter

Field of invention

The present invention relates to a method and a device for removing contaminants from liquids and gasses The invention particularly relates to filtering of wastewater and drinking water containing unwanted solutes and solids with diameter < approximately 250 µm All patent and non-patent references cited in the present application, are hereby incorporated by reference in their entirety

Background of invention

Filters for removing polluting components from liquid and gas are known from the prior art Filtration is usually understood as a process of separating dispersed particles, and some times solutes too, from a dispersing fluid by drawing the fluid across a porous medium The invention described here is in this respect not a true filtration in that the fluid is not drawn across the porous medium, but flows along it without crossing it

Traditional filters suffer from the dilemma that on one hand they need to have an open structure in order to retain a certain hydraulic conductivity, but on the other hand the structure must not be too open in order to retain dispersed particles and solutes Traditional filters also suffer from gradually falling hydraulic conductivity (pressure drop) as more and more particles are trapped within the filter medium Clogging rather than use-up of filter capacity often determines the frequency of filter regeneration of replacement

One type of filters is based on a layered structure with different pore sizes and sorption capacities in the layers The liquid or gas moves through the layers of these known filters sequentially, most often first through one or more macroporous layers to remove particulate material and then through one or more microporous layers having the capacity to absorb dissolved or dispersed material The drawback of these filters is mainly that materials with low hydraulic capacity (and high absorptive capacity) cannot be used under practical circumstances, because the flow rate will be too low Another drawback is that once the filtering capacity of the microporous

layer in just one spot is exhausted, then the whole layer must be exchanged, because the filter will leak pollutants

Another embodiment of filter units with two types of pores is one where micro- and macropores are mixed throughout the filterlayer Such filters consist of particles (e g perlite) or other macrostructures, which contain micropores Macropores are formed between the particles These filters generally may have a higher rate of flow through the filter, because the pollutants are trapped in the micropores, whereas the main flow is through the macropores These filter units are inherently non-uniform, because the size of the macropores is determined by the dimensions of the particles/structures containing the micropores Thus there is a risk that pores of too great size are created through the layers so that polluted liquid can run through the filter without coming into contact with the micropores This may especially be the case along the outer boundaries of the filter layer, e g along the side of a container housing the particles/structures In such a filter, it is not possible to place a sorbent of choice in the micropore region and the filter therefor cannot be adapted to remove a pollutant of choice

US 6,080,307 (ABTECH INDUSTRIES) discloses a storm drain insert with a separate collection system for oil and other hydrocarbons The filtermaterial consists of a copolymer of thermoplastic polymers such as styrene-butadiene-styrene The filtermaterial according to one embodiment is formed as a cylindrical body with a centrally placed hole along its longitudinal body The cylindrical bodies may have numerous fissures to increase the effective surface of the body

US 5,788,849 (HUTTER & PROBST) discloses a filter unit containing several filter components, wherein the filter components are placed in a horizontal orientation and thereby perpendicular to the direction of flow of the water The hydraulic conductivity of such a filter unit is determined by the hydraulic conductivity of the filter component with the smallest pore size As filter materials with a high absorptive capacity inherently have a low hydraulic capacity a filter unit based on this design has a low hydraulic conductivity

US 5,776,567 (PACTEC INC) discloses a multi-layer filter for separating solid and liquid wastes In a preferred embodiment the filter includes four layers The first

layer may be a network of parallel strands The second layer may be a fibrous mat, the third layer a netting like the first layer and the fourth layer a porous filter cloth During use, water passes sequentially through the layers under the force of gravity and water without solids can be drained from the bottom of the filter As in other multi-layered filters, the hydraulic conductivity of the filter unit is determined by the layer having the lowest conductivity Filtermaterial with a low hydraulic conductivity cannot be used for such a filter

US 5,632,889 (THARP) discloses a filter cartridge for separating liquid hydrocarbons from water The filter cartridge comprises perlite particles which have been treated with a silicone Runoff water may percolate through a body of particulate perlite so that hydrocarbons are absorbed by the perlite particles and pure water can be drained from the bottom of the filter One disadvantage of this filter unit is that it is confined to perlite particles and therefore not useful for removing pollutants, which are not absorbed by perlite Furthermore, at pointed out above there is a potential risk that larger pores are created through the layer, so that part of the liquid by-passes the filter without coming into contact with the inside of the perlite particles

US 4,761,232 (POREX TECHNOLOGIES CORP) discloses a macroporous polyethylene substrate defining a network of interconnecting macropores and a microporous matrix of polyvinyl chloride, which completely fills the network of macropores This filter has many features in common with the perlite filter disclosed in US 5,632,889 since it also consists of a network of intermingled macro and micropores One drawback of such a filter layout is that the microporous matrix cannot be removed independently from the macroporous substrate, when the absorptive capacity of the former is exhausted Furthermore, the whole filter has to be exchanged as soon as the absorptive capacity of the micropores has been exhausted in just one location

US 5,980,761 (BOISSIE ET AL) discloses a filter unit being cylindrical or frustoconical and containing pozzolan as a particulate filter material The water to be filtered may pass in a direction both vertically through the unit and in a horizontal direction In the case of two or more different filter materials, the water passes sequentially through the layers Thus the filter is a special embodiment of a traditional multi-layered filter

Definitions

Convective layer – is defined according to the present invention as a layer with a high hydraulic conductivity It is an open structure that allows the contaminated fluid to flow through the filter In the layout of the convective layer there will be a main direction of flow along one axis In most embodiments, the convective layer is flat (e g in the shape of a sheet having a defined thickness) The axis of main direction of flow in the convective layer is along the long axis of the layer, not in a direction perpendicularly across the layer

Stagnant layer – is defined as a layer with a low or zero hydraulic conductivity in the direction parallel to the main direction of flow as defined by the convective layer The stagnant layer is open for diffusion of solutes and colloids, and for sedimentation of particles, and and can either transfer or retain pollutants The hydraulic conductivity of the convective layer is at least ten times the hydraulic conductivity of the stagnant layer in the main flow direction

The difference in hydraulic conductivity between the layers along the axis of the main direction of flow in the convective layer is at least a factor 2, more preferably at least a factor 10, more preferably at least a factor 10^2, more preferably at least 10^3, more preferably at least 10^4, such as at least 10^5, for example at least 10^6

Pollutants – (unwanted components) – the filter unit according to the present invention work by diffusion and sedimentation Any component that can be moved by diffusion or sedimentation can thus be removed from liquid or gas according to the present invention This includes any solute or solvent and particles small enough to enter the convective layer Dissolved matter and particles up to 1-2 µm (colloids) can be trapped by diffusion into the stagnant layer, while larger particles (up to approximately 250 µm) can enter the stagnant layer by gravitational sedimentation Larger particles must not be allowed to enter the filter unit

Summary of invention

It is one object of the invention to provide a filter having a high and independently determined hydraulic capacity during the whole lifetime of the filter and yet having a high capacity for retaining the pollutants, which it is designed to retain

Accordingly, there is provided a filter, wherein the filter medium is not percolated by the fluid, but merely is adjacent to the fluid The fluid (gas or liquid) to be purified is conducted along the stagnant layer containing the filter medium by means of the convective layer Pollutants are removed from the fluid by means of diffusion and sedimentation into the stagnant layer The stagnant layer typically contains material to withhold the polluting components to be removed from the liquid or gas In special cases the stagnant layer merely allows the pollutant(s) to diffuse across it, e g in order to be picked up by another type of fluid flowing through the next adjacent convective layer In other cases the stagnant layer contains stagnant water only, e g for trapping sediment A layer of stagnant water can be obtained by e g confining the desired volume of water by an impermeable frame, or by filling a desired volume with a material having a low hydraulic conductivity

Matter is primarily transported between the two layers via diffusion, and sedimentation Convective flow of fluid into the stagnant layer is insignificant, or restricted to specific designs or functions of the filter, e g alternating high and low flow conditions, or re-saturation of the filter after dewatering

One prominent advantage of the filter according to the present invention is that a high hydraulic capacity can be achieved irrespective of the filter material used This is due to the presence of the convective layer, which can be chosen to give any hydraulic conductivity It is thus possible to filter huge amounts of liquid or gas and still use a filter material with a very low hydraulic conductivity It is also possible to dimension the filter to have a low hydraulic capacity where this is desired or useful

By retaining the pollutants along the direction of flow in a separate layer the classical problem with clogging of the filter is avoided Thus, the initial hydraulic conductivity of the filter is maintained through out the entire lifetime of the filter

Another advantage of introducing a specific convective layer in the filter is that the energy needed for driving the fluid through the filter is low Thus in many cases the fluid may be driven by gravity In other cases, a pump may be used to drive the fluid through the filter unit

By appropriate design of the stagnant layer a filter is provided that simultaneously combats solutes and small particles Solutes are removed by diffusion into the stagnant layers above and below the convective layer The stagnant layer must contain an appropriate sorbent in order to retain the solute Small particles are trapped by sedimentation in the stagnant layer below the convective layer The stagnant layer must be given a structure that allows for appropriate storage of the sediment

By separating the sorptive units, i e the stagnant layers, from the flow, i e the convective layer, the choice of filtermaterial is rendered more free, since the problem with low hydraulic conductivity has been solved For this reason, filter materials with very low hydraulic conductivity and also filters which do not have the structure to be e g self supporting can be used provided that the convective layer has the required structure In a stacked design of alternating convective and stagnant layers, a filter can be built, where individual layers serve individual purposes Stagnant layers with different features can be built into the same filter Also different convective layers can conduct different fluids, which can interact by diffusion through the stagnant layers Altogether this gives a very flexible purification device, that can be given almost unlimited designs

The invention provides a filter alternative that treats equally well fluids with high and low, or even alternating, pollutant loads Thus, the influent pollutant concentrations will always be reduced by the same factor on leaving the filter, irrespective of the input concentration If a higher reduction factor is wanted the device should either be made longer in order to provide a longer residence time, or the width of the convective layer should be reduced, thereby providing a shorter diffusion distance and a shorter sedimentation distance

Description of Drawings

Figure 1a Schematic representation of a dual porosity filter with one convective layer between two stagnant layers The figure illustrates the principle of pollutant removal through diffusion driven by concentration gradients

Figure 1b Schematic representation of a dual porosity filter with one convective layer between two stagnant layers The figure illustrates the principle of pollutant removal through sedimentation driven by gravity

Figure 2 Example of construction for road runoff treatment in dual porosity filter

Detailed description of the invention

The working principle of the filter units and methods according to the invention is illustrated with reference to Figures 1a and 1b In figure 1a is shown a cross section of a filter unit with one convective layer and two stagnant layers The stagnant layers are separated by distance "d", being equal to the thickness of the convective layer Pollulants illustrated by black dots are transported into the filter through the convective layer and diffuse due to concentration gradients into the stagnant layer, where the pollutants are trapped, absorbed or adsorbed The maximum distance that the pollutants have to move to get into the stagnant layers is ½d, i e the diffusion distance

In Figure 1b is illustrated the working principle of the filter units for removing suspended matter, e g particles that do not move by diffusion The layout of the filter unit of Figure 1b is the same as for Figure 1a For ease of illustration, only suspended matter is shown in the convective layer, but of course it is to be understood that one and the same filter unit will remove pollutants both through diffusion and sedimentation The suspended pollutants can only sediment in the direction of gravity, i e to the stagnant layer below the convective layer The suspended particles have to move a maximum distance of "d" equal to the thickness of the convective layer to be caught in a stagnant layer

Stagnant layer

The stagnant layer is either a single structure that in its own porosity impairs a low hydraulic conductivity in the main direction of flow, or a composite structure where hydraulic features are obtained isolated from the sorptive, and/or sedimentative features, for instance a grid-like structure filled with sorptive material An unlimited number of organic and inorganic materials can be used as sorbent for removal of e g heavy metals and organic pollutants, e g sand, gravel, perlite, vermiculite, anthracite, activated carbon, charcoal, diatomaceous soil, chitin, chitosan, pozzolan, lime, marble, clay, iron-oxide-coated minerals, e g sand, double metal-hydroxides, LECA, rockwool, zeolithes, fly ash, soil, limed soil, iron-enriched soil, bark, lignin, compost, seaweed, algae, alginate, xanthate, peat moss, bone gelatin beads, moss, wool, cotton, other plant fibres, and modification hereof Even trapped sediment may in some cases serve as sorbent for solutes The material chosen for the stagnant layer depends of course on the pollutants to be removed Information concerning suitability of materials for different pollutants can be found in the literature see e g
Jobstmann, H and Singh, B 2001 Cadmium sorption by hydroxy-aluminium interlayered montmorillonite Water, Air, and Soil Pollution 131 203-215
Cohen-Shoel, N , Barkay, Z , Ilzyucer, D , Gilath, I and Tel-Or, E 2002 Biofiltration of toxic elements by Azolla biomass Water, Air, and Soil Pollution 135 93-104
Johansson, L 1997 The use of Leca (Light Expanded Clay Aggregates) for the removal of phosphorus from wastewater Water Science and Technology, 35 87-93Ouki, S K and Kavannagh, M 1997 Performance of natural zeolithes for the treatment of mixed metal-contaminated effluents Waste Management & Research, 15 383-394
Bailey, S E , Olin, T J , Bricka, R M and Adrain, D D 1999 A review of potentially low-cost sorbents for heavy metals Water Research, 33 2469-2479

The thickness of the stagnant layer is set in accordance with the amount of pollutant that it should be able to carry In principle there is no upper limit for the thickness of stagnant layer, but for practical reasons it is often kept below 50 cm More often the thickness is kept between 1 mm and 20 cm, such as 1-2 cm, for example 2-3 cm, such as 3-4 cm, for example 4-5 cm, such as 5-6 cm, for example 6-7 cm, such as 7-8 cm, for example 8-9 cm, such as 9-10 cm, for example 10-12 cm, such as 12-14 cm, for example 14-16 cm, such as 16-18 cm, for example 18-20 cm The

dimensions for some purposes may also be kept within 20-25 cm, 25-30 cm, 30-35 cm, 35-40 cm or 40-50 cm Pollutants initially trapped in the part of the stagnant layer adjacent the convective layer, will diffuse deeper into the parts of the stagnant layer, which are further removed from the convective layer, so that new pollutants can be trapped

Convective layer

The convective layer can be constructed either as a simple spacing of two adjacent stagnant layers, perhaps obtained by equipping the two adjacent stagnant layers with small 'nails' giving just the desired spacing, or it may be composed of a specific structure, e g a folded, open-structured net like the central part of the EnkaDrain The main purpose of the physical structures employed is to guarantee a specific minimum aperture of the convective layer, which is needed for dimensioning the filter

The material is preferably a non-absorbent, water-permeable, fibrous mesh material formed with circuitous (non-linear) pathways therethrough The material is preferably a mass of random filament-type plastic fibers with a density which is sufficient to support the filter unit without significant collapse, but allow water to pass freely therethrough A possible embodiment of the material is a polyethylene or polyester fibrous mesh such as ENKADRAIN E8004H75-2s/D110P manufactured by Colbond Geosynthetics, Arnhem, the Netherlands Another material is FIBERBOND EM 6645 manufactured by Fiberbond in Michigan City, Ind The material may be of two or more different materials or layers

In some instances, a more open fiber-material will be desired One such material is KemWove 8643, available from KemWove The material is described in U S Pat No 5,423,992, incorporated herein by reference

The convective layer may alternatively comprises a mass of open-structured plant fibers with a density which is sufficient to support the filter unit without significant collapse, but allow water to pass freely therethrough Plant fibers can be pressed into a form-stable mat and the use of such materials can be very interesting for

relatively short-lived filters Suitable plant fibers include bark, chunk-wood, chip-wood, or straw

The thickness of the convective layer is selected in dependency of the residence time in the filter unit and the flow rate of the liquid or gas The dimensions of the convective layer is normally considerably lower than the stagnant layer, in order to keep the sedimentation/diffusion distance as low as possible In a filter for liquids the thickness is normally kept within 1 mm to 5 cm, more preferably between 1 mm and 3 cm, such as 1 mm to 2 cm, more preferably below 1 cm, such as 9 mm, 8 mm, 7 mm, 6 mm, 5 mm, 4 mm, 3 mm, 2 mm It is generally preferable to have a relatively short spacing between the stagnant layers (the spacing determining the thickness of the convective layer) in order to keep the diffusion/sedimentation distance as short as possible

In a filter for gas filtration the dimensions of the convective layer is considerably lower and is normally kept within 0 1 mm and 2 mm

Filter layout

The physical layout of the filter unit, in its simplest form is one convective layer adjacent to one stagnant layer In order to increase the capacity of the filter unit it may be built up in a sandwich form, with one convective layer sandwiched between two stagnant layers In this way pollutants can be removed through diffusion in two directions A further increase in capacity is obtained by using a stacked form, with many alternating layers of convective and stagnant layers A further embodiment of the filter is a stacked form with different purpose alternating layers of convective and stagnant layers

A stacked form can be made simply by stacking the alternating layers, but it can also conveniently be made by rolling a filter unit with one convective layer surrounded by one or two stagnant layers and thus obtain a filter roll

A sandwich filter may be stacked to increase the capacity and the throughput The higher the number of filters in the stack, and/or the wider the stack, the higher the capacity and the higher the throughput A filter unit may thus comprise a stack of

sandwich filters, the stack comprising at least 2 sandwich filters, such as at least 3 sandwich filters, for example at least 4 sandwich filters, such as at least 5 sandwich filters, for example at least 6 sandwich filters, such as at least 7 sandwich filters, for example at least 8 sandwich filters, such as at least 9 sandwich filters, for example at least 10 sandwich filters, such as at least 12 sandwich filters, for example at least 15 sandwich filters, such as at least 20 sandwich filters, for example at least 25 sandwich filters

A filter unit according to the invention may also comprise a stack of alternating convective/stagnant layers to increase the capacity and throughput The filter unit may thus comprise a stack of at least 2 convective/stagnant layers, such as at least 3 layers, for example at least 4 layers, such as at least 5 layers, for example at least 6 layers, such as at least 7 layers, for example at least 8 layers, such as at least 9 layers, for example at least 10 layers, such as at least 12 layers, for example at least 15 layers, such as at least 20 layers, for example at least 25 layers

A stacked filter is preferably separated from the surroundings, e g the ground by a water-impermeable layer In some embodiments the impermeable layer surrounds the filter unit to seal it from the surroundings on all surfaces except the inlet and outlet

A roll of a filter unit may have at least two rounds, such as at least 3 rounds, for example at least 4 rounds, such as at least 5 rounds, for example at least 6 rounds, such as at least 7 rounds, for example 8 rounds, such as at least 9 rounds, for example at least 10 rounds, such as at least 12 rounds, for example at least 15 rounds, such as at least 20 rounds, for example at least 25 rounds of stagnant/convective layer or stagnant/convective/stagnant layer The higher the number of rounds the higher the hydraulic capacity A rolled filter is preferably isolated from its surroundings by coating it with a water-impermeable layer

It is often preferable when determining the dimensions of the filter unit, to use a filter unit with many layers/rounds instead of using fewer layers/rounds with thicker layers, because the diffusion/sedimentation distance must be taken into account Thus often instead of doubling the layer thickness, it is preferable to use a stacked

filter unit, in which the pollutants have to move a shorter distance to be trapped in the stagnant layer

Flow

Water and/or gas can be transported through the filter in various ways A convenient way for a road runoff filter is to use gravity to obtain a give flow rate, but a pump may also be used to obtain an increased flow rate or an up-hill flow if desired Gravity may be used to drive fluid through the filter unit by using a hydraulic gradient of 1 to 10% This corresponds to giving the filter a slope of 1 to 10 cm per meter along the direction of flow

Dimensioning of the filter unit

The dimensions of the filter unit include the following thickness of the stagnant and convective layers, length of the filter unit, width of the filter unit, number of layers (if stacked), number of rounds (if rolled)

The dimensions of the filter unit are determined by a number of factors, which can be measured and/or decided and used for calculating the dimensions These factors include diffusion coefficient and/or sedimentation coefficient for the pollutant, amount of pollutant in the water/gas entering the filter, desired reduction in amount of pollutant (% reduction or reduction factor), flow rate in the convective layer Using formulae known in the art, it is possible to calculate the specific dimensions Reference is made to the examples for a specific calculation

Once a specific residence time has been calculated from a pollution reduction claim, the dimensions of length and hydraulic head may be interchanged, i e decreasing the hydraulic head can compensate for a shorter length and vice-versa Filter width is dimensioned to meet the influent flow rate Filter width can be reduced by stacking layers

Hydraulic head in general, is the elevation of a water body above a particular datum level Specifically, it is the energy possessed by a unit weight of water at any particular point The hydraulic head consists of three parts the elevation head,

defined with reference to a standard level or datum, the pressure head, defined with reference to atmospheric pressure, and the velocity head Water invariably flows from points of larger hydraulic head to points of lower head, down the hydraulic gradient

Use of the filter units

The filter units according to the present invention can be used for filtering almost any kind of liquid from which larger particles have been removed first An illustrative and non-limiting list of liquids include waste water, industrial waste water (pharma, oil, chemical, metal, food and feed industry), urban waste water, highway runoff, stormwater

With suitable dimensioning the filter units may likewise be used for filtering gas Examples include but are not limited to flue gas, combustion engine exhausts, industrial exhausts, industrial waste gasses, ventilation air from production facilities, such as e g pig production

The components that can be removed using the present invention include any pollutant for which a stagnant layer can be designed Unwanted components include but are not limited to hydrocarbons, oil, heavy metals, hormones, PAH, pesticides, pharmaceuticals, MTBE, inorganic ions (nitrite, nitrate, phosphate, sodium), colloids (corresponding to a size fraction of 0 1 to 2 μm), small particles, BAM, chlorinated solvents

A road runoff dual porosity filter unit

Reference is now made to Figure 2 in which a road runoff filter unit is schematically illustrated The road-runoff enters the filter unit at the left side from a pre-sedimentation unit, which is needed to remove coarse material (> 250μm in diameter) such as sand, gravel, leaves and other debris The filter unit consists of a total of 10 convective layers separated from one another and surrounded by stagnant layers for sorption and sedimentation of pollutants An impermeable membrane on the bottom ensures that liquid does not leak from the filter unit Each

of the convective layers is adapted to take a flow of 0 0025 m^3/second Altogether the filter unit can work with a flow up to 0 025m^3/second

The illustrated filter unit is 60 m wide and 100 m long, but these figures are merely for illustrative purposes There is an inclination of 1 meter, giving a hydraulic gradient of 0 01 As polluted water enters the Inlet construction on the left it starts floating through the lower convective layer In periods of high flow, more layers become active These will then dry out in periods of less flow, but they will still retain the captured pollutants The outlet construction is constructed so that it can cope with the variation in flow When the flow is low, pure water leaves the unit from the lower reduced outlet In periods of high flow, the water leaves the unit both from the lower and the higher outlet

Examples

Example 1 Road runoff filtration

Road runoff is characterised by erratic, but often large and rapid flows Its pollution load is characterised by comprising particles, colloids and solutes in most variable concentrations The solutes may comprise both organic contaminants like mineral oil and PAH, and inorganic contaminants like heavy metals and phosphate By forcing the road runoff to perform a sheet like flow through convective layers of the filter the conditions for solute diffusion and particle sedimentation into stagnant water bodies in the stagnant layer is optimised The stagnant layer can be provided simply by use of a grid like structure, for instance a 5 cm high grating with mask width in the range of millimetres, equipped with a bottom membrane that is open to diffusion of solutes, but closed for particles with diameter > e g 20 µm Convective layer Velvet nylon net, like the central part of an Enkadrain 8004H/5-2s/D110P, which has a width of 4 mm At a 1% hydraulic gradient a convective layer like this has a hydraulic capacity of 0 042 l/s per meter

Stagnant layer A grate-like structure, e g a large scraper, made of wood, plastic or another water impermeable material The grate can be filled with a sorbent, e g ironoxide coated sand

At a flow rate of incoming solution of 0 005 m^3/s the filter width, d_{filter}, is calculated as

$$d_{filter} = (0\ 005/0\ 000042)\ m^3/s = 119\ m$$

The flow rate within the convective layer, q, is

$$q = 0\ 005 m^3/s\ /\ (119 * 0\ 004)\ m^2 = 0\ 0105\ m/s$$

If a 20 times reduction in influent concentrations of e g heavy metals is wanted the filter length must be approximately 180 m This is calculated from an average diffusion coefficient for heavy metals of 0 7 E-9 m^2/s, an average diffusion distance, x, of 0 002 m (half the convective layer width), and an assumption that the diffusion gradient, dC/dx, caused by differences in solute concentration in the convective layer and in the stagnant layer is unchanged during the filtration, that is, the sorbent in the stagnant layer is capable of keeping the solution concentration very low, irrespective of the amount of solute accumulated in the stagnant layer This is a reasonable assumption in that heavy metals are held strongly by many sorbents The loss of mass of dissolved heavy metals is proportional to the available diffusive area, A, the diffusion coefficient, dc, of the metal, the residence time, t, and the diffusion gradient, dC/dx To make the calculation, we now consider a packet of water as it passes through the filter The water packet has the dimensions of 1 m width, 4 mm high and reaches 10 5 mm into the filter, giving a volume of 0 000042 m^3 This gives a residence time for the water packet of 1 s in each step The corresponding diffusive area A is 0 021 m^2 (1m * 0 0105 m * 2) The concentration of dissolved heavy metal in the influent is set to 200 mg/m^3 During the first second of residence in the filter the loss of mass of heavy metal will be

Step 1

loss of mass of heavy metal= A * dc * t * dC/dx = 0 021m2 * 0 7*E-9m^2/s * 1s * (200/0 002)mg/m^4 = 0 00000147 mg

new input concentration for step 2 = [(200 mg/m^3) * 0 000042 m^3 – 0 00000147 mg]/0 000042 m^3 = 199 97 mg /m^3

This is the new concentration of the water packet as it enters the next centimetre of the filter

Step 2

loss of mass of heavy metal = A * dc * t * dC/dx = 0 021m^2 * 0 7*E-9m^2/s * 1s * (199 97/0 002)mg/m^4 = 0 00000147 mg

new input concentration for step 2 = [(199 97 mg/m^3) * 0 000042 m^3 – 0 00000147 mg]/0 000042 m^3 = 199 93 mg /m^3

This is the new concentration of the water packet as it enters the third centimetre of the filter

By continuing this stepwise calculation it is seen that a concentration of 10 mg/m3 is reached after approximately 180 m of progression with a filter with these dimensions If a reduction factor of 10 is satisfying the corresponding filter length reduces to approximately 140 m

Due to the diffusion gradient gradually becoming smaller as the water packet becomes more and more clean (depleted of heavy metal) the loss gradually also reduces, corresponding to an exponential decline in treatment rate with filter length

Similar calculations can be made for the sedimentation of suspended material by applying Stokes Law

Claims

1 A method for removing pollutants from a liquid or gas comprising

i providing a filter comprising at least one convective layer and at least one stagnant layer adjacent one another,

ii passing the liquid or gas through the filter so that the main direction of flow is along the layers and the main flow of liquid or gas is in the convective layer, allowing the dissolved pollutants to diffuse into the stagnant layer(s)

2 The method according to claim 1, wherein a stagnant layer is positioned below the convective layer to allow particulate pollutants to sediment into the stagnant layer

3 The method according to any of the preceding claims, where the stagnant layer further has an affinity for the solutes

4 The method according to claim 1, where the stagnant layer comprises at least one micro-organism capable of converting the component

5 The method according to claim 1, where the components move by diffusion from the stagnant layer into a second convective layer adjacent the stagnant layer and opposite the first convective layer

6 The method according to claim 1, where the filter further comprises a second stagnant layer adjacent the convective layer and opposite the first stagnant layer

7 The method according to claim 1, where at least one stagnant layer comprises material selected from the list consisting of sand, gravel, perlite, vermiculite, anthracite, activated carbon, charcoal, limed soil, iron-enriched soil, diatomaceous soil, chitin, chitosan, pozzolan, lime, marble, clay, iron-oxide-coated minerals, e g sand, double metal-hydroxides, LECA, rockwool, zeolithes, fly ash, soil, bark, lignin, compost, seaweed, algae, alginate, xanthate, peat moss, bone gelatin beads, moss, wool, cotton, other plant fibres, and modification hereof

8 The method according to any of the preceding claims, wherein a stagnant layer comprises trapped sediment as a sorbent

9 The method according to any of the preceding claims, wherein the convective layer consisting of a non-absorbent, water-permeable, fibrous mesh material formed with circuitous pathways therethrough

10 The method according to any of the preceding claims, wherein the convective layer comprises a mass of random filament-type plastic fibers with a density which is sufficient to support the filter unit without significant collapse, but allow water to pass freely therethrough

11 The method according to claim 10, wherein the convective layer comprises a polyethylene or polyester fibrous mesh

12 The method according to claim 11, wherein the convective layer comprises ENKADRAIN 8004H/5-2s/D110P manufactured by Colbond Geosynthetics, Arnhem, the Netherlands

13 The method according to claim 11, wherein the convective layer comprises FIBERBOND EM 6645 manufactured by Fiberbond in Michigan City, Ind

14 The method according to any of the preceding claims, wherein the convective layer comprises a mass of open-structured plant fibers with a density which is sufficient to support the filter unit without significant collapse, but allow water to pass freely therethrough

15 The method according to claim 14, wherein the plant fibers comprise a mat of bark, chunk-wood, chip-wood, or straw

16 The method according to any of the preceding claims, wherein the hydraulic conductivity of the convective layer is at least two times the hydraulic conductivity of the stagnant layer in the main flow direction

17 The method according to any of the preceding claims, wherein the difference in hydraulic conductivity between the stagnant and convective layer along the axis of the main direction of flow in the connective layer is at least a factor 2, more preferably at least a factor 10, more preferably at least a factor 10^2, more preferably at least 10^3, more preferably at least 10^4, such as at least 10^5, for example at least 10^6

18 The method according to claim 1, wherein the liquid to be filtered comprises waste water, industrial waste water (pharma, oil, chemical, metal, food and feed industry), urban waste water, highway runoff, stormwater

19 The method according to any of the preceding claims, wherein the liquid to be filtered comprises urban waste water, highway runoff, road runoff and/or stormwater

20 The method according to any of the preceding claims, wherein the pollutant is selected from the group consisting of hydrocarbons, oil, heavy metals, hormones, PAH, pesticides, pharmaceuticals, MTBE, inorganic ions (nitrite, nitrate, phosphate, sodium), colloids below 20 µm, BAM, chlorinated solvents

21 The method according to claim 1, further comprising passing the liquid or gas through a pre-filter to remove particulate material prior to the filtering steps of claim 1

22 The method according to claim 21, wherein particulate material with a mean size above 250 µm is removed

23 A filter unit for filtering liquid or gas comprising

i at least one convective layer,

ii at least one stagnant layer adjacent said convective layer,

iii at least one impermeable layer preventing the flow of liquid or gas through the layers in a direction perpendicular to the layers and sequentially through the layers

24 The filter unit according to claim 23, further comprising a second stagnant layer adjacent the convective layer opposite the at least one stagnant layer, being a sandwich filter

25 The filter unit according to claim 24, comprising a stack of sandwich filters, the stack comprising at least 2 sandwich filters, such as at least 3 sandwich filters, for example at least 4 sandwich filters, such as at least 5 sandwich filters, for example at least 6 sandwich filters, such as at least 7 sandwich filters, for example at least 8 sandwich filters, such as at least 9 sandwich filters, for example at least 10 sandwich filters, such as at least 12 sandwich filters, for example at least 15 sandwich filters, such as at least 20 sandwich filters, for example at least 25 sandwich filters

26 The filter unit according to claim 23, comprising a stack of alternating convective/stagnant layers

27 The filter unit according to claim 26, comprising a stack of at least 2 convective/stagnant layers, such as at least 3 layers, for example at least 4 layers, such as at least 5 layers, for example at least 6 layers, such as at least 7 layers, for example at least 8 layers, such as at least 9 layers, for example at least 10 layers, such as at least 12 layers, for example at least 15 layers, such as at least 20 layers, for example at least 25 layers

28 The filter unit according to claim 23, wherein the impermeable layer surrounds the filter unit to seal it from the surroundings on all surfaces except the inlet and outlet

29 The filter unit according to claim 23, wherein the stagnant layers is selected from the group consisting of sand, gravel, perlite, vermiculite, anthracite, activated carbon, charcoal, soil, limed soil, iron-enriched soil, diatomaceous soil, chitin, chitosan, pozzolan, lime, marble, clay, iron-oxide-coated minerals, e g sand, double metal-hydroxides, LECA, rockwool, zeolithes, fly ash, soil, bark, lignin, compost, seaweed, algae, alginate, xanthate, peat moss, bone gelatin beads, moss, wool, cotton, other plant fibres, and modification hereof

30 The filter unit according to claim 23, wherein a stagnant layer comprises trapped sediment as a sorbent

31 The filter unit according to claim 23, wherein the convective layer consisting of a non-absorbent, water-permeable, fibrous mesh material formed with circuitous pathways therethrough

32 The filter unit according to claim 23, wherein the convective layer comprises a mass of random filament-type plastic fibers with a density which is sufficient to support the filter unit without significant collapse, but allow water to pass freely therethrough

33 The filter unit according to claim 23, wherein the convective layer comprises a polyethylene or polyester fibrous mesh

34 The filter unit according to claim 23, wherein the convective layer comprises ENKADRAIN 8004H/5-2s/D110P manufactured by Colbond Geosynthetics, Arnhem, the Netherlands

35 The filter unit according to claim 23, wherein the convective layer comprises FIBERBOND EM 6645 manufactured by Fiberbond in Michigan City, Ind

36 The filter unit according to claim 23, wherein the convective layer comprises a mass of open-structured plant fibers with a density which is sufficient to support the filter unit without significant collapse, but allow water to pass freely therethrough

37 The filter unit according to claim 36, wherein the plant fibers comprise a mat of bark, chunk-wood, chip-wood, or straw

38 The filter unit according to claim 23, wherein the hydraulic conductivity of the convective layer is at least two times the hydraulic conductivity of the stagnant layer in the main flow direction, more preferably at least ten times

39 The filter unit according to claim 23, wherein the difference in hydraulic conductivity between the stagnant and convective layer along the axis of the main direction of flow in the connective layer is at least a factor 10, more preferably at least a factor 10^2, more preferably at least 10^3, more preferably at least 10^4, such as at least 10^5, for example at least 10^6

40 The filter unit according to claim 23, being in the form of a roll

41 The filter unit according to claim 40, having at least two rounds, such as at least 3 rounds, for example at least 4 rounds, such as at least 5 rounds, for example at least 6 rounds, such as at least 7 rounds, for example 8 rounds, such as at least 9 rounds, for example at least 10 rounds, such as at least 12 rounds, for example at least 15 rounds, such as at least 20 rounds, for example at least 25 rounds of stagnant/convective layer or stagnant/convective/stagnant layer

42 The filter unit according to claim 23, further comprising a pump for pumping liquid or gas through the filter unit

43 The filter unit according to claim 23, further comprising a pre-filter adapted to remove particulate material from the liquid or gas prior to passing the liquid or gas into the filter unit according to claim 23

44 The filter unit according to claim 43, wherein the pre-filter is adapted to remove particles above 250 µm

45 Use of the filter unit according to claims 23 to 43 for filtering wastewater

46 The use of claim 45, wherein the wastewater is stormwater runoff, stormwater drain, highway runoff, urban runoff, urban stormwater,

47 Use of the filter unit according to claims 23 to 43 for filtering gas (flue gas, waste gas, exhaust gas)

Diffusion

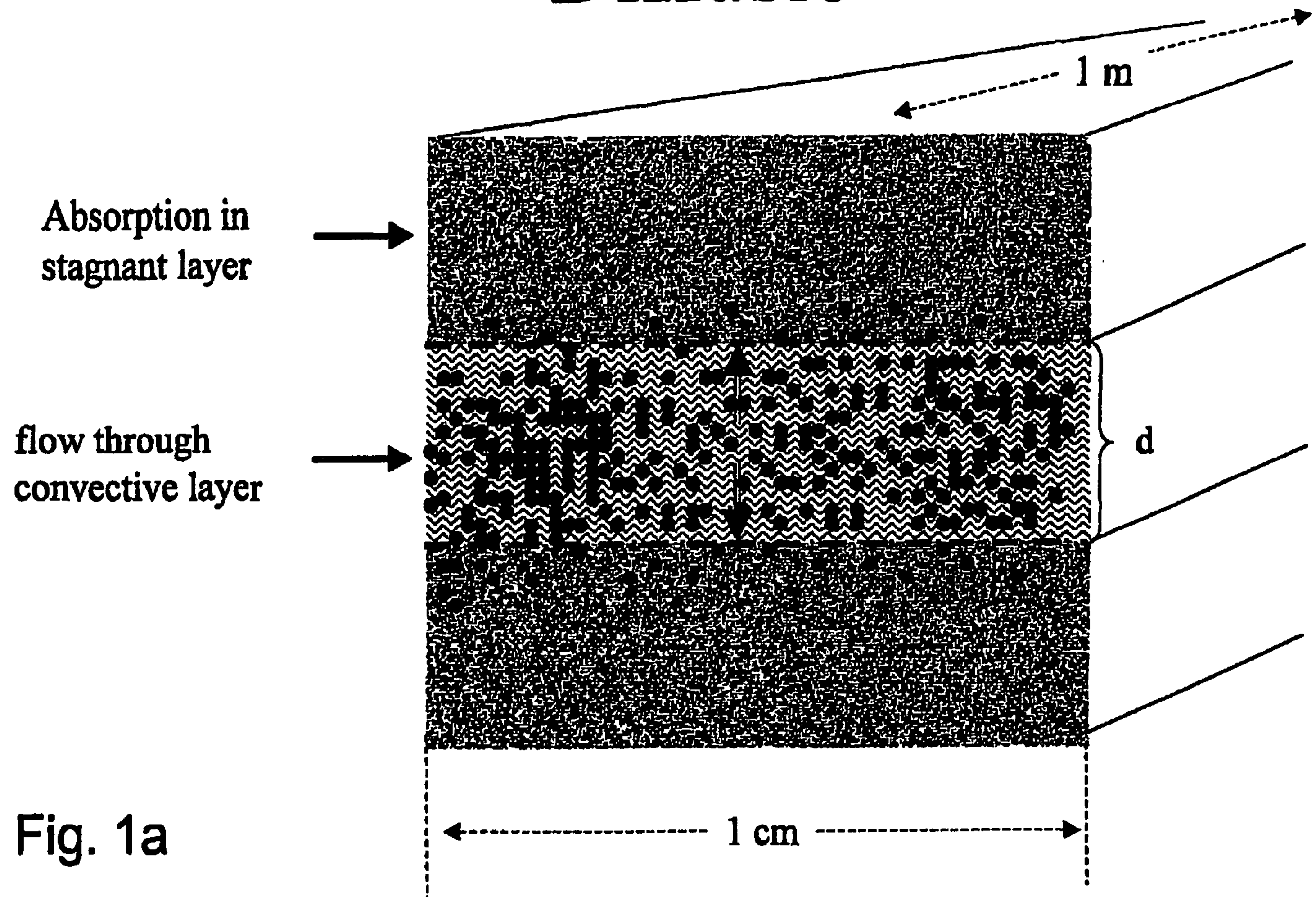

Fig. 1a

diffusion distance = ½d

Sedimentation

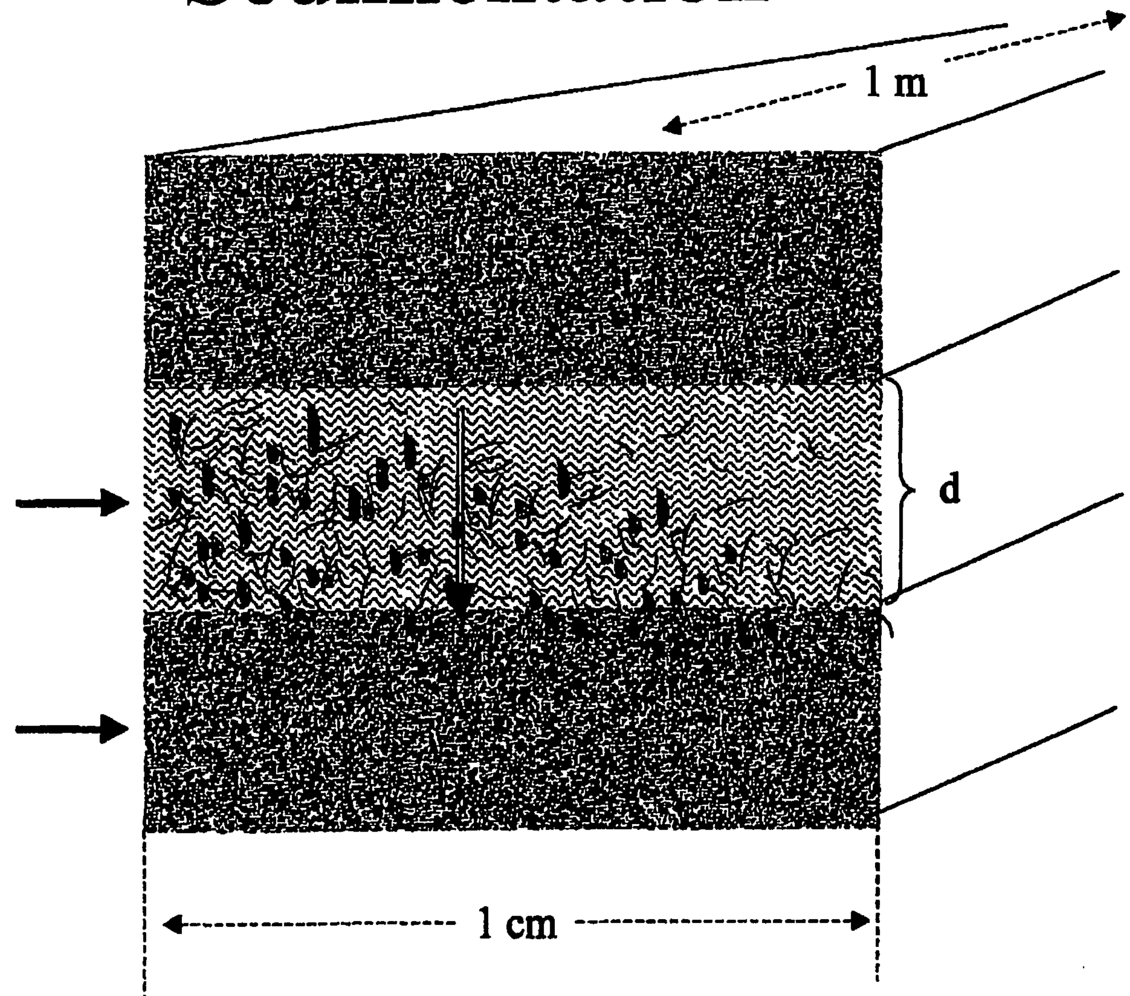

Fig. 1b

sedimentation distance = d

Fig. 2 Schematic representation of a road runoff dual porosity filter unit